

# **How Much Water Passes through the Indonesian Passages?**

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## **LONG-TERM GOALS**

The goal of this project is to obtain a more thorough understanding of the dynamics of the Indonesian Throughflow. We plan to establish new flow rate laws for currents forced through an arrangement of islands.

## **OBJECTIVES**

I am conducting analytical and numerical investigations of the Indonesian throughflow and plan to make comparisons of the results with data presently being collected as part of Arlindo II. ["Arlindo II" is a cooperative project of the U.S. and Indonesia. The abbreviation ARLINDO originates in Malay and stands for: avarus (sea), lintas (flow) and Indonesian.] In particular, we are completing the examination of (1) the amount of water that can be forced through a single gap, and (2) the distribution of such flows through a "porous" wall containing a number of gaps. The interest is in the application of the above calculations to warm (and fresh) Pacific waters exiting from the Indonesian Seas through the Lombok Strait, the Alor Strait and the Timor Passage.

The nature of my modeling work is that I simultaneously work on several projects; some of these projects are not necessarily closely related to each other. For this reason, some of the publications which are listed at the end of this report may appear to be somewhat disjointed.

## **WORK COMPLETED**

Analysis of the Throughflow's origin, and an analysis of the maximum flow rate that a broad gap on a beta-plane can handle.

## **RESULTS**

Research has resulted in the preparation and publication of several papers, listed at the end of this report in the order that they were completed. Most have not been supported solely by ONR but also by NSF and NASA. The papers that are most closely related to the Throughflow study are #3, #4 and #7. The most important aspect of these articles is the finding that all of the Indonesian Throughflow must be upwelled into the thermocline somewhere along the equatorial Pacific.

In what follows I describe a detailed summary of the results (arranged in the order that the manuscripts have been completed during the past two years).

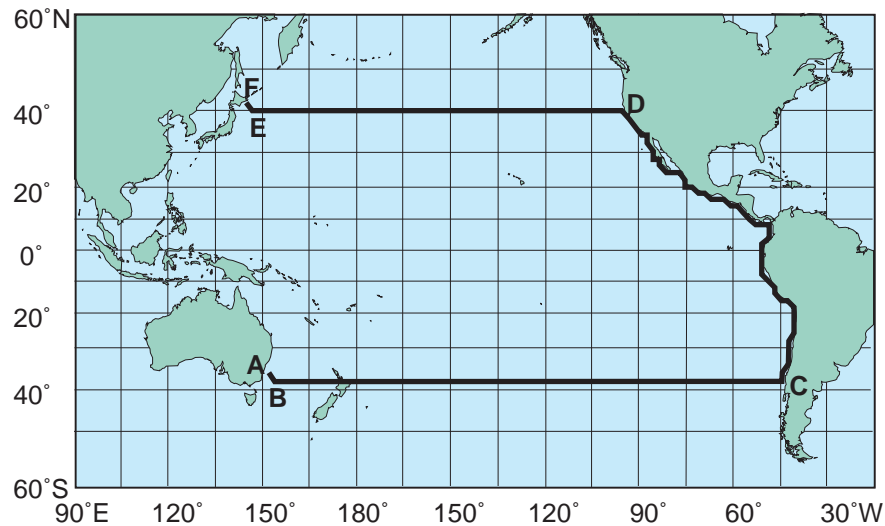
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First, we looked at the separation of western boundary currents, with particular application to the collision and separation of the Brazil and Malvinas Currents (paper #1). We determined that the observed migrations of the separation latitude may be caused by seasonal changes of the Malvinas Current transport. In paper #2 we examined the question of how deep ocean eddies can cross the equator and, with analytical and numerical models, determined that the geometry of the channel and the presence of the equator determine how the fluid will be partitioned among the two hemispheres.

Paper #3 examined the exchange of water between hemispheres by looking at the behavior of continuous (double frontal) abyssal currents situated on the bottom of a meridional channel. We determined that the inter-hemispheric exchange is primarily an inertial process that depends mainly on the channel geometry.

The "separation formula," a new method for computing the inter-hemispheric meridional transport, was applied to the Pacific Ocean integrating the equations of motion along the path shown in Figure 1 (paper #4). The model suggested that the observed Pacific to Indian throughflow is a measure of the upwelling (or cooling) in the Pacific. We then proposed a new theory for the generation of the Tsugaru and Alboran gyres (paper #5). The generation of these gyres is caused by the (otherwise imbalanced) flow force of the long-shore current downstream regardless of the initial current vorticity. Next, we applied a previously developed model describing the intimate relationship between retroflecting currents and the production of rings (Nof and Pichevin, 1996, *Journal of Physical Oceanography*, v. 26, 2344-2358) to the Agulhas Current (paper #6). We showed that the generation of rings from a retroflecting current is inevitable, and that there is no obvious relationship between the presence of so-called "Natal Pulses" and the production of rings.

The next study explored the nonlinear eastward propagation rate of the so-called Pacific warm pool, the region of high, sea-surface temperature associated with El Nino (paper #7). Typical values for the Pacific give a bounding propagation rate of 50-60 cm/s which is in good agreement with the observed migration rate during both the 1982-83 El Nino and the 1997 El Nino, the only ones in history that are known to result from an almost complete relaxation of the winds. Using a simple analytical model to compute the meridional warm water flux in the Atlantic (paper #8), we illustrated that a significant part of the water in the Global Conveyor Belt that ultimately sinks in the north Atlantic is of intermediate (cold) and not surface (warm) origin. The next study (paper #9) examined the impingement of a westward drifting lens-like anticyclonic ring on a meridional boundary. We found that a ring encountering a wall stays roughly in a fixed latitude rather than moving poleward, gradually leaking fluid toward the equator until it loses all of its mass. We concluded that rings such as warm-core Gulf Stream rings, Loop Current rings, Agulhas rings, as well as other eddies (e.g., Meddies) may behave in this fashion. Last, we examined the reason for the small transport within the Sea of Japan relative to that of the Caribbean and discovered that the reason for this difference is its relatively high latitude and not the size of the gaps connecting it to the Pacific Ocean (paper #10).



**Figure 1.** *The horseshoe integration path ABCDEF in the throughflow model study (paper #4). Sections AB and EF are perpendicular to the boundary currents, whereas BC and ED are zonal sections. The integration of the COAD wind stress was done in 2° squares.*

## IMPACT/APPLICATIONS

The results of our calculations for the single gap problem are formulas relating the transport through the gap to its width, latitude, depth and the sea-level difference between the connecting basins. Similarly, the multiple gap problem will yield formulas relating the relative transport that passes through each of the passages (i.e., the percentage of the total transport that a given passage can handle) to the size of each gap, the size and location of the adjacent gaps and the sea-level difference between the connecting basins. This useful information will then be compared to the actual transport calculated from shallow pressure gauges which will be available by the time that the theory is completed. The combination of these two independent means of computation will enable us to better understand the dynamics of the throughflow. Without this combination it is doubtful that a thorough understanding can be achieved.

## RELATED PROJECTS

This project is closely related to the NSF project #OCE-9503816 entitled "Flows through multiple gaps with applications to the Indonesian Throughflow." However, this NSF grant supports the study of the western rather than the eastern passages which are the focus of the ONR grant. Also, the NASA project #NAGW-4883 entitled "Studies of Variable Climate Processes" examines the exchange of surface water between the Indian and Pacific Oceans.

## **PUBLICATIONS**

1. Lebedev, I. and D. Nof, 1997: Collision of boundary currents: Beyond a steady state. *Deep-Sea Research*, 44, 771-791.
2. Borisov, S. and D. Nof, 1998: Deep, cross-equatorial eddies. *Geophysical and Astrophysical Fluid Dynamics*, 87, 273-310.
3. Nof, D. and S. Borisov, 1998: Inter-hemispheric oceanic exchange. *Quarterly Journal of the Royal Meteorological Society*, in press.
4. Nof, D., 1998: The 'separation formula' and the Indonesian Throughflow. *Deep-Sea Research*, in press.
5. Nof, D. and T. Pichevin, 1998: The establishment of the Tsugaru and the Alboran gyres. *Journal of Physical Oceanography*, in press.
6. Pichevin, T., D. Nof and J. Lutjeharms, 1998: Why are there Agulhas rings? *Journal of Physical Oceanography*, in press.
7. Nof, D. and S. Van Gorder, 1998: Intense nonlinear migrations of the Pacific warm pool. *Deep-Sea Research*, submitted.
8. Nof, D. and S. Van Gorder, 1998: A different perspective on the export of water from the South Atlantic. *Journal of Physical Oceanography*, in press.
9. Nof, D., 1998: Strange encounters of eddies with walls. *Journal of Marine Research*, submitted.
10. Nof, D., 1998: Why much of the circulation in the Atlantic enters the Caribbean Sea and very little of the Pacific circulation enters the Sea of Japan. *Journal of Physical Oceanography*, submitted.